ATTACHMENT A

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Preliminary information on cod and haddock production in submerged cages off the coast of New Hampshire, USA

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The University of New Hampshire's Open Ocean Aquaculture project is intended to evaluate the potential development of offshore aquaculture in the northeastern United States. As part of this project, both cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) were raised in submerged cages at an exposed location 14 km off the coast of New Hampshire, USA. In September 2003, at a mean weight of 45 g, 30 000 cod were transferred offshore into a 200-m^3 nursery net located inside a 3000-m^3 cage submerged 12 m below the surface. Cod were later released into the main cage at a mean weight of 90 g and are intended to be grown to a market size of 2–3 kg. As of February 2005, the cod averaged 652 g, had a 92% survival rate, an FCR of 1.49, and an SGR of 0.49% d^{-1}. Haddock research was initiated in mid-September 2002, when 3000 haddock (16 g mean weight) were transferred to a 35-m^3 inshore nursery pen. By mid-December 2002, their mean weight had increased to 78 g, and the fish were transferred to an offshore cage. As of February 2005, the haddock had a survival rate of 92%, mean weight of 1360 g, FCR of 2.36, and SGR of 0.35% d^{-1}.

Keywords: cod culture, haddock culture, offshore cages.

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Introduction

Several events have heightened interest in marine finfish aquaculture in New England. The first has been the near collapse of traditional groundfish fisheries (Clark, 1998). This situation has created doubt about the long-term availability of fishery products and has caused some harvesters to seek alternative professions. The second has been the large number of documented successes in aquaculture throughout the world. Finally, the region's largest aquaculture industry, namely Atlantic salmon (*Salmo salar*), is experiencing economic hardship because of increasing worldwide production, and this has created an interest in rearing alternative marine species (LeFrancois *et al.*, 2002).

While much has been accomplished over the past decade, there are still significant biological and technical issues that must be resolved if aquaculture is to expand and prosper in New England. Among the most significant of these issues is the paucity of sites suitable for commercial-scale aquaculture. Inshore coastal waters are used heavily for recreation, commercial fishing, and shipping, limiting the growth of aquaculture facilities in these areas. Offshore sites provide an alternative that presents fewer conflicts with existing user groups. Other benefits include better water quality, better dispersion of farm effluents, and more space for production. In addition, when the cages are submerged, the fish benefit from a more stable thermal regime (less seasonal variation in temperature), and protection from storm events. Finally, there is less wear on submerged gear, less bio-fouling, and virtually no user conflict or visual impact. The major disadvantage is that the wind and sea conditions of such exposed locations present technical challenges in the design and construction of aquaculture systems capable of surviving in these areas. Further, there are significant difficulties associated with monitoring and caring for the fish.

Hatcheries for groundfish, including cod and haddock, were established in the United States, Norway, and Canada towards the end of the 19th century when stocks began to show signs of depletion (Earll, 1880; Solemdal *et al.*, 1984). The goal of these hatcheries was to produce larvae

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for release to the sea, on the assumption that such additions would rebuild wild populations. Although these efforts were abandoned in the mid-20th century when this stock rebuilding strategy came into question (Svåsand *et al.*, 2000), a lasting benefit from these efforts was the development of the fundamental techniques for the culture of the early life-history stages of many marine finfish species. A review of the early information on cod culture can be found in a two-volume set edited by Dahl *et al.* (1984), and "culture manuals" have been provided by Huse (1991) and Holm *et al.* (1993).

Declines of wild populations have brought a renewed interest in cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) aquaculture. Commercial and experimental farms in Norway, Canada, and the United Kingdom have been established. The limited data from the commercial ventures are very encouraging (Braaten, 1984; Pedersen and Jobling, 1989; Howell, 1996). For example, there is an indication that cultured cod grow two to five times faster than wild fish, and that fish reared in net pens can reach 2 kg in 20 months and 3 kg in 36 months (Braaten, 1984). Experimental growth rates are equally impressive. For example, Lambert and Dutil (2001) found that small cod (approximately 500 g) grew 25–45% per month depending on stocking density, while Clark *et al.* (1995) observed 8–11% growth per month for larger fish (approximately 2 kg) held in net pens.

Less work has been done on haddock than cod, in part because haddock is not a preferred species of Europeans. There is, however, considerable interest in haddock aquaculture in both New England and Atlantic Canada (Litvak, 1998). The species is cold tolerant, grows fairly rapidly, can be grown in salmon cages, and has a good market price. Summaries of culture techniques are available in Waiwood (1994) and Frantsi *et al.* (2002). The rapid advancement of haddock aquaculture resulted from a partnership between a large commercial salmon company (Heritage Salmon Limited) and several Canadian government research laboratories. Members of this partnership have made significant progress in broodstock management and spawning, egg and larval rearing, the development of weaning and grow-out diets, and on-growing methodologies. Their experience has shown that juveniles of 3–5 g can be stocked into inshore net pens, and that they reach market size (2–2.5 kg) at about three years of age (Frantsi *et al.*, 2002). Despite the initial advances in haddock culture, many obstacles remain, including large-scale larval culture (Harmon *et al.*, 2003), practical feeds and nutrition (Lall *et al.*, 2003), and outbreaks of viral nervous necrosis (Buchan, 2003; Harmon *et al.*, 2003; Merritt, 2003).

In 1997, the University of New Hampshire established the Open Ocean Aquaculture demonstration project (OOA). The overall goal of the OOA project is to evaluate and potentially stimulate the further development of commercial aquaculture in New England, thereby increasing seafood production, creating new employment opportunities, and contributing to economic and community development. The multi-year, regional project has been investigating the suitability of net pen designs and cold-water marine fish and shellfish species for commercial-scale production. The goal of the research is to develop and demonstrate environmentally responsible and economically viable culture practices for marine fish and bivalves for the northeastern United States. The aim of this paper is to describe the preliminary findings on cod and haddock production in submerged sea cages off the coast of New Hampshire.

Methods and material

Cod production

Cod juveniles were produced in a series of stages associated with different culture facilities and systems. Great Bay Aquaculture, LLC (GBA), produced 30 000 juveniles for the study. In December 2002, wild adult cod were collected from the Gulf of Maine and transferred to holding tanks at GBA. There, the fish were sexed and tagged, and 125-mg salmonid GnRHA implants were injected into the nape of mature females. Samples from the wild cod broodstock (both sperm and eggs) tested negative for viral nervous necrosis. Cod were raised at GBA until they were 3–5 g in size (May 2003). Prior to transfer to sea cages, juveniles were inspected by veterinary pathologists, certified for transfer into the tidal waters of New Hampshire, and vaccinated with a commercial bacterin against *Vibrio* spp. A representative sample of 100 juveniles was weighed and measured to obtain final sizes before transfer from the hatchery. Finally, the fish were acclimated to the cooler ocean temperatures by reducing tank temperature and deprived of food for a minimum of 48 h prior to transport.

The second stage of production occurred in nearshore nursery pens where the fish were able to acclimate to natural conditions. Cod were moved from the hatchery into 35-m^3 net pens located near the University of New Hampshire's Coastal Marine Laboratory (CML) in New Castle, New Hampshire. The net pens were constructed of high density polyethylene (HDPE), measured 4.5 × 4.5 × 2.8 m, and had a mesh size of 5 mm. Ten thousand juvenile cod were stocked into each of three nursery net pens at a density of 1.1 kg m^{-3}. This is similar to the density (2 kg m^{-3}) that has been shown to produce maximum specific growth rates for 500–600-g cod (Lambert and Dutil, 2001). Mortality, ability to maintain position in the tidal current, feeding behaviour, and growth rate were monitored. As the cod grew, larger mesh (1.2 cm and 2.5 cm stretch) nets were sequentially installed to increase water exchange and maintain high oxygen levels within the pens. Initially the fish in the nursery net pens were hand fed to satiation four times daily to maximize growth and minimize cannibalism. Eventually, solar powered, 12-V automatic feeders, each consisting of a 40-kg polyethylene

hopper, an auger, and a digital timer, were used to feed a daily ration approximately equal to 3% of the fish biomass. Feed rations were adjusted as body size and water temperature increased. A subsample of 25–50 fish was measured and weighed biweekly to calculate growth rates and feed conversion efficiencies. As the fish grew, stocking densities were reduced by transferring fish to additional net pens. The juvenile cod remained in the nursery pens until attaining a mean weight of 45 g (September 2003). Density in each of the five nursery pens at this time was 7.5 kg m^{-3}. The 30 000 fish were relocated via a smolt transfer vessel, in September 2003, to a 200-m^3 nursery net located within an offshore 3000-m^3 cage. The final stage of production is ongoing in this 3000-m^3 Sea Station™ cage.

The cod were fed both Zeigler and Skretting commercial diets consisting of 15% lipid and 50–55% protein. Pellet size has ranged from 2 mm in the nursery pens up to 6.5 mm offshore. Pellet size will increase to 12 mm diameter as the fish grow, and fish will be fed to satiation (1–2% of body weight) every 1–3 days, depending on water temperature (Huse, 1991). To prevent early sexual maturation, which reduces subsequent growth (Dahle *et al.*, 2000; Karlsen *et al.*, 2000; Hansen *et al.*, 2001), we equipped the cod net pen with three continuously illuminated, submersible metal halide lights. Each 400 W light produces 90 lm W^{-1}. Light levels measured ranged from 2 to 600 lux, varying with location in the net pen and time of day. Technical difficulties have prevented illumination of the cage since late December 2004. Although some of the fish will be harvested in the spring of 2005 to test a live, small fish market, we anticipate that most of the fish will be harvested in the autumn of 2005, at 32 months of age. Based on the experiences of pilot scale cod farms in Norway (Braaten, 1984), the average weight of the fish should be about 2–3 kg at this time. Assuming a high survival rate, total weight of fish in the pen near the time of harvest will approach 60 000–90 000 kg. This results in a harvest density of approximately 20–30 kg m^{-3}, which has permitted reasonably good growth (Lambert and Dutil, 2001). Upon harvesting, all fish will be enumerated and weighed to enable precise quantification of survival, growth, and feed conversion during culture in the net pen. The harvested fish will be transported to the Portsmouth Fishermen's Cooperative in Portsmouth, New Hampshire, where they will be processed and sent to market.

Haddock production

The haddock study commenced in the spring of 2002 when approximately 3000 haddock (16 g mean weight), through a collaborative research agreement with Heritage Salmon Limited, New Brunswick, Canada, were transferred from the National Research Council Laboratory in Halifax, Nova Scotia, Canada and stocked into a nearshore, 35-m^3 nursery pen located in New Hampshire. In December 2002, the 77-g fish were moved offshore to a submerged, 600-m^3 Sea Station™ cage.

Two composite underwater video cameras (Norcan Electrical Systems Inc.) provided real time images to the Jere Chase Ocean Lab at the University of New Hampshire. This enabled biologists and managers to observe feeding behaviour and adjust feed rations. There were no underwater lights to control photoperiod in the haddock cage. The haddock, ranging from 4 mm to 9 mm, were fed either Zeigler or Skretting diets. Both these diets consisted of 50–55% protein and 15–17% lipid.

Since stocking, we monitored haddock growth by taking approximately monthly samples for body weight and length. We anticipate that these fish will remain in this net pen until November 2005, when they will be harvested (2–3 kg). This will be the first time that haddock have been raised in an exposed, offshore location.

Culture systems

Cod are being raised in a 3000-m^3 Sea Station™ cage (25 m wide × 16 m deep), while the haddock are contained in a 600-m^3 Sea Station™ cage (15 m wide × 9 m deep). A four grid, submerged mooring platform maintains the cages and two automatic feed buoys (Figure 1). Nets Systems Inc. (Bainbridge, Washington, USA) manufactured the Sea Station™ cages. This unique, submersible culture system can be operated at the surface or in a subsurface position. The bi-conical design utilizes a very taut, Spectra™ netting to maintain the integrity of the central spar and steel rim (Figure 2). The central spar controls the buoyancy of the cage, allowing it to be raised or lowered in the water column. The cage maintains its upright position by utilizing a 5450-kg pendant weight attached to the bottom of the spar. During normal operating conditions, the cages are submerged 12 m below the ocean's surface. This is the depth recommended by the United States Coast Guard for the safe passage of recreational and commercial vessels over the cages.

Feed buoys

A 1-tonne capacity, diesel powered, experimental feed buoy provided daily feed rations to the submerged cod cage (Figure 3). The buoy is maintained at the surface in a two-point mooring, adjacent to the cage, and the feed dosing system was remotely controlled from the University. A rotary air lock dropped the feed pellets into a mixing chamber before they were pumped through a 10-cm diameter flexible PVC hose, to the cage, 50 m away. Feed was delivered daily in 7-kg pulses over a 1-h period. The haddock cage was fed by a 500-kg capacity automatic feed buoy, powered by solar and wind electricity generation (Figure 3). A high stretch, rubber feed hose, developed by Woods Hole Oceanographic Institute, delivered feed from the buoy to

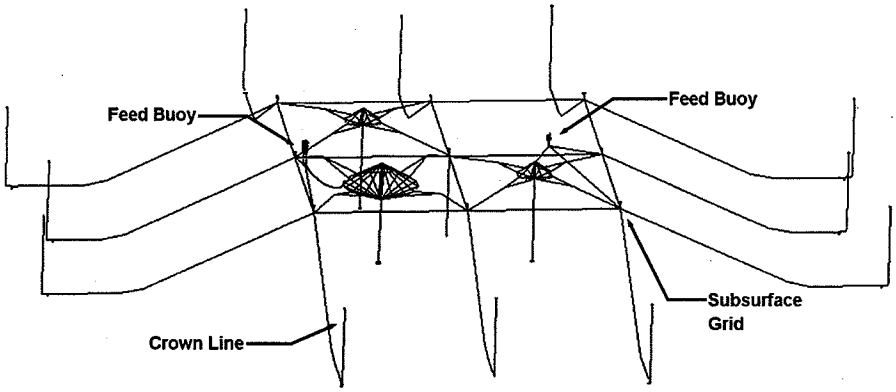

Figure 1. Diagram of the University of New Hampshire submerged mooring platform located in 52-m water depth. The mooring is spread over 12 ha and maintains the cod (bottom left) and haddock (bottom right) cages and two automatic feed buoys.

the fish cage. Feed was mixed with water before it was pumped down to the cage 12 m below.

Data collection

Cod and haddock growths have been quantified by measuring total length and body weight of a representative sample of 25–50 fish at approximately monthly intervals. These data, along with records of amounts of feed provided, were used to calculate gross feed conversion ratios [FCR = F/W, where F is the total weight of food fed and W is (the final mean weight − the initial mean weight) × the number of fish], and gross specific growth rate (SGR = $[(\ln W_2 - \ln W_1)/t] \times 100$), where W_1 and W_2 are initial and final weights respectively, and t is the time in days between weighing). Gonosomatic index (GSI) and hepatosomatic index (HSI), which are the percentages of total wet weight comprised by the gonads and liver, respectively, have been measured from 50 randomly chosen fish at several sampling intervals.

Sampling from 2-atmospheres depth is difficult with gadoid species because the fish's swimbladder inflates and can rupture as the individual is brought to the surface for measurement. A decompression scheme was implemented to reduce the stress of capture, ascent, and sampling before transfer back to the submerged cage. Fish were netted by divers and placed in a small cage (1 × 0.5 × 0.25 m) and suspended above the cage at <1 atmosphere (8 m). The

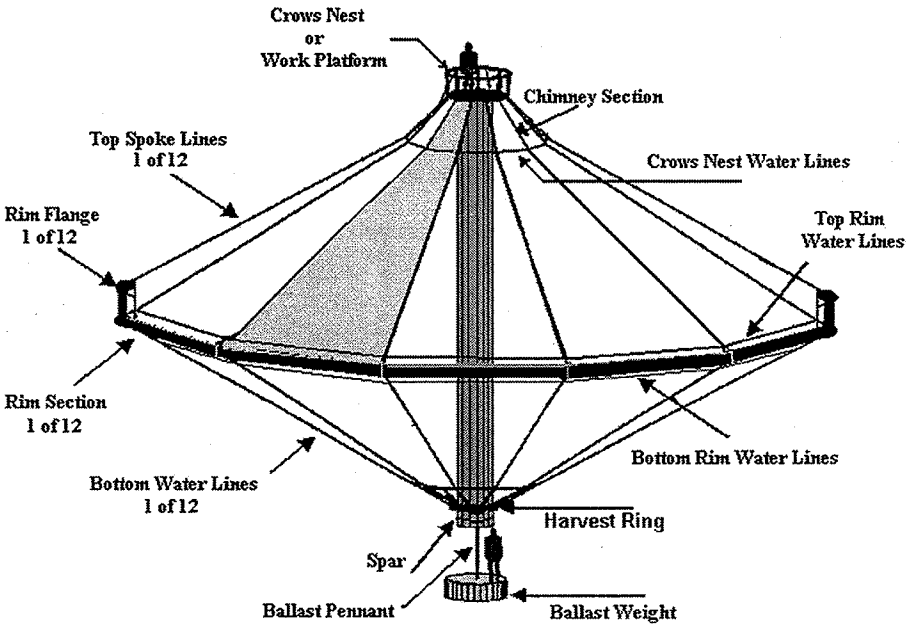

Figure 2. A schematic of the general configuration of a 3000-m^3 Sea Station™ cage. The cage diameter is 25 m and height is 15.5 m.

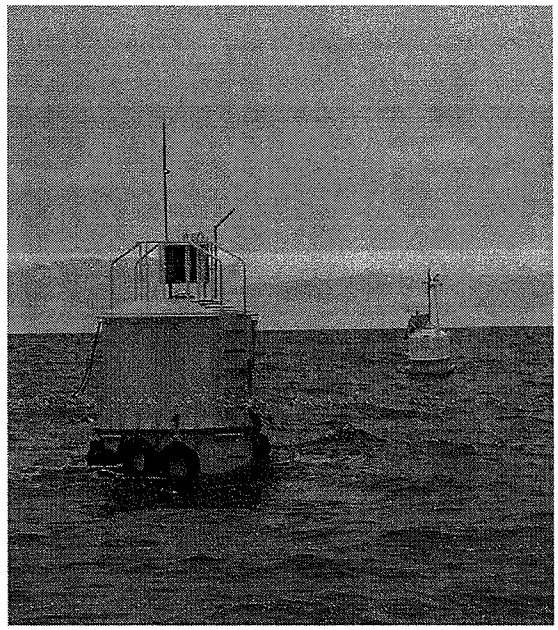

Figure 3. University of New Hampshire feed buoys for cod (left) and haddock (right).

Table 1. Characteristics of cod maintained in nearshore and offshore sites.

Site	Nearshore	Offshore
Duration	29 April 2003	7 September 2003 –23 February 2005
Cage size (m^3)	35	3 000
Initial weight (g)	3.2 ± 0.25	45 ± 7.7
Initial length (cm)	—	16.5 ± 0.7
Age at stock (d)	119	260
Stock density ($kg\,m^{-3}$)	1.1	0.5
Temperature range (°C)	4.0–17.0	2.0–11.5
Survival (%)	97	92
Days in culture	131	537
Weight (g)	45 ± 7.7	652.0 ± 156.0*
Length (cm)	16.5 ± 0.7	39.3 ± 2.3*
Harvest density ($kg\,m^{-3}$)	7.5	To be determined
FCR	1.40	1.49
SGR ($\%\,d^{-1}$)	1.87	0.49
HSI (% BW)	8.2 ± 0.9	8.6 ± 1.9*
Female GSI (% BW)	—	7.9 ± 4.1*

*Measured 25 February 2005.

fish were allowed to decompress for 24 h before they were brought near the surface (2 m) for 1 h prior to sampling. This method has resulted in no over-inflation of the swimbladders and allows fish to be returned to their culture environment without injury.

Results

Cod growth data are presented in Table 1 and weight gain over time is provided in Figure 4. The 30 000 cod (3.2 g mean) transferred from GBA were maintained in 35-m^3 nearshore nursery cages for 131 days until they were approximately 45 g mean weight. Survival nearshore was 97% and the SGR was $1.87\%\,d^{-1}$. The fish were transferred offshore in September 2003 and had grown from 45 g to 652 g as of February 2005 (537 days growth). Survival as of 25 February 2005 was 92%, and the SGR for the entire offshore period was $0.49\%\,d^{-1}$. Feeding occurred at a rate of two to three times a week at approximately 1% $BW\,d^{-1}$ during winter/spring and $1.5\%\,BW\,d^{-1}$ during summer/autumn. Temperature ranges were 4.0–17.0°C in the nearshore nursery pens compared with 2.0–11.5°C offshore. In both environments, the HSI has been below 9%. Female GSI was less than 4% through late November 2004, but increased to 7.9% by February 2005. Feed conversion ratios averaged 1.49 at inshore and offshore sites.

Haddock growth data are presented in Table 2, and weight gain over time is shown in Figure 5. The haddock were transferred from Halifax, Canada, to New Hampshire, USA, in 1-m^3 oxygenated seawater containers, at a density of $22.2\,kg\,m^{-3}$. Survival during this 14-h transfer was 100%. Similar survival occurred when the fish were transferred from nearshore nursery pens to the offshore cage (600 m^3) at a density of $34\,kg\,m^{-3}$. The fish were maintained in the nearshore nursery pen (35 m^3) for 90 days before being stocked offshore at a mean weight of 77 g. Haddock survival at the offshore pen has been 92%. Specific growth rate in the nearshore pens was $1.7\%\,d^{-1}$ compared, with $0.35\%\,d^{-1}$ at the offshore cage. The feed conversion ratio nearshore was 1.3, compared with 2.36 in the offshore cage. HSI, as of February 2005, was 13.4%. Female GSI increased dramatically between late November 2004 (2.7%) and February 2005 (13.0%), and virtually all ovaries contained some hydrated eggs. No diseases have been observed to date with either the cod or haddock offshore.

Discussion

Preliminary results indicate that both species are well suited for open ocean aquaculture. A number of advantages have been observed in growing gadoids in a submerged environment. They include less seasonal variation in water temperature (maximum 14°C in the submerged cage vs. 20°C at surface), less bio-fouling of the cages, and protection from turbulence associated with storms.

No other project has attempted to culture gadoids so far from land and in a completely submerged culture system. Thus, comparisons of growth can only be made with fish reared in inshore net pens or the laboratory. Huse (1991) stated that farmed cod grew two to five times faster than natural stocks in the North Atlantic. He also established

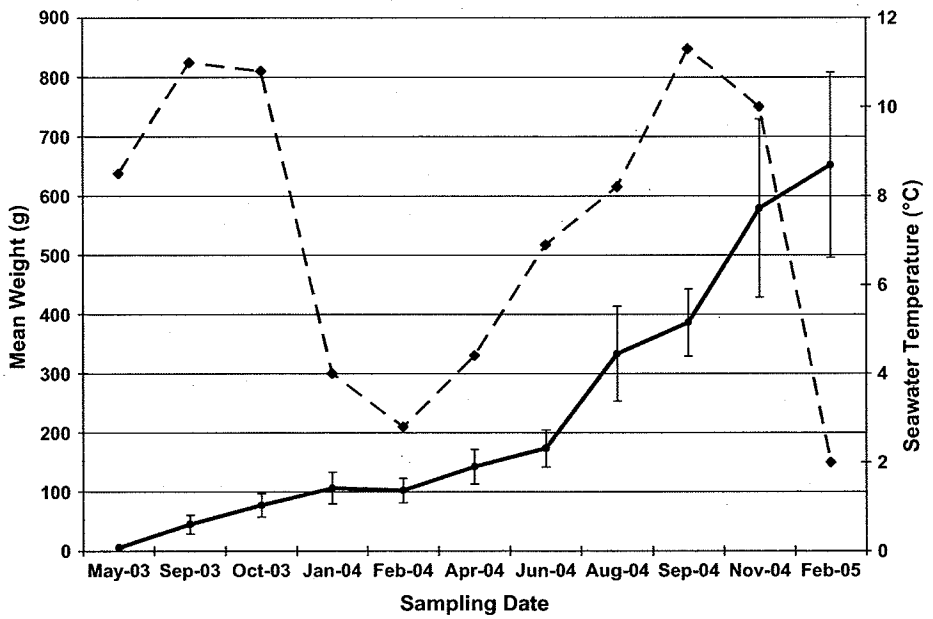

Figure 4. Monthly changes in body weight of cod (solid) and water temperature (dashed). Vertical lines are ±1 s.d.

growth curves that suggest that cod grow to 2 kg in 20 months, followed by a decrease in growth at sexual maturity. Fish are predicted to reach 3 kg after three years, similar to the Björnsson and Steinarsson (2002) growth model. Our cod appear to be slightly behind this estimation, possibly as a result of initial slow growth over a long, cold, first winter (<3 °C for 3 months). Compounding the cold temperatures was insufficient feeding caused by mechanical issues with a newly deployed feed buoy. This problem was overcome in spring 2004 and has led to more consistent daily feed delivery.

Lambert and Dutil (2000) noted that during maturation, which usually occurs at two years of age in farmed cod (Karlsen *et al.*, 1995), the fish lost 30% of their weight despite acceptable levels of food intake. Studies conducted by Hansen *et al.* (2001) indicated that light manipulation can postpone first maturation by 6–12 months. As indicated, we installed three, 400-W submersible lights (in the fall of 2004) to suppress early maturation. The mean female GSI of our 24-month-old fish (7.9%) was below the 10–20% GSI values of cod that are near spawning (Hansen *et al.*, 2001), and only a small percentage of the ovaries examined contained hydrated oocytes. Thus, it seems that the submersible lights, although nonfunctional for a period of time, were effective at delaying sexual maturity, but they may not inhibit maturity completely.

According to Björnsson *et al.* (2001), the optimal temperature for cod growth and feed conversion decreases with size, from 17 °C for 2-g fish to 7 °C for 2-kg fish. Their research also provided growth rates of different sized cod at different temperatures. Our growth rate offshore, 0.6% d^{-1} at 7 °C, was similar to growth rates observed in the laboratory, which range from 0.5 to 0.7% d^{-1} (Björnsson *et al.*, 2001; Hansen *et al.*, 2001), for similarly sized fish. Further, our growth rates coincide with model calculations of unlimited-food growth rates predicted by Björnsson and Steinarsson (2002). We conclude from these data that our cod show similar growth to those grown under other conditions, and

Table 2. Characteristics of haddock maintained in nearshore and offshore sites.

Site	Nearshore	Offshore
Duration	13 September 2002	18 December 2002 –25 February 2005
Cage size (m^3)	35	600
Initial weight (g)	16.7 ± 5.2	77.9 ± 12.7
Initial length (cm)	12.1 ± 1.6	18.5 ± 1.1
Age (d)	201	291
Stock density (kg m^{-3})	1.4	0.4
Temperature range (°C)	6.0–14.0	1.3–11.0
Survival (%)	97	92
Days in culture	90	799
Weight (g)	77.9 ± 12.7	1 360.5 ± 337.0*
Length (cm)	18.5 ± 1.1	44.0 ± 3.7*
Harvest density (kg m^{-3})	6.5	To be determined
FCR	1.30	2.36
SGR (% d^{-1})	1.71	0.35
HSI (% BW)	—	13.4 ± 3.1*
Female GSI (% BW)	—	13.0 ± 1.6*

*Measured 25 February 2005.

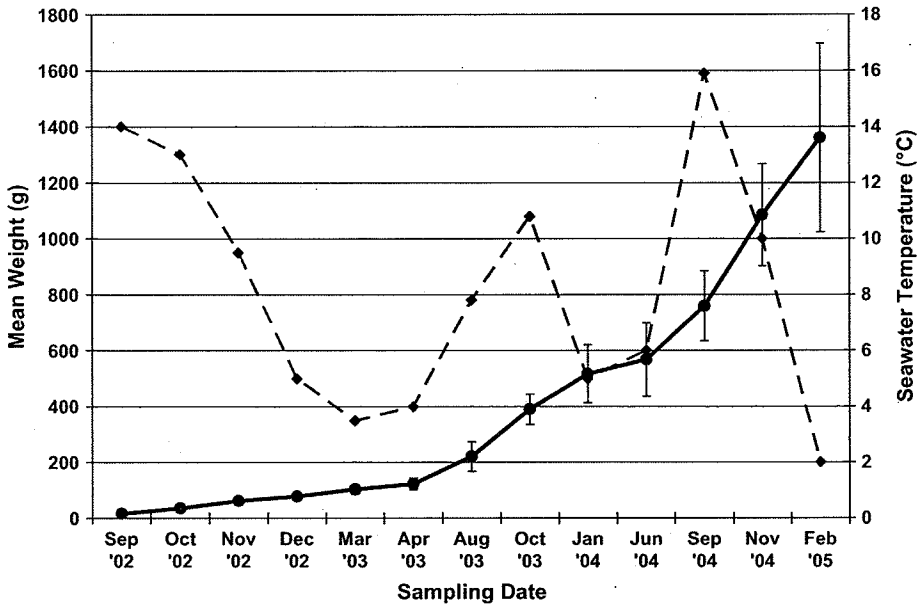

Figure 5. Monthly changes in body weight of haddock (solid) and water temperature (dashed). Vertical lines are ±1 s.d.

thus that cod production in submerged, offshore cages from a growth perspective is potentially viable.

Offshore haddock culture appears to be successful thus far. Still, much more information is necessary in order for this species to become a profitable aquaculture candidate. Commercialization constraints for this species include optimizing growth rates and lack of cage sites (Frantsi *et al.*, 2002; Lall *et al.*, 2003). Our haddock growth rates have been similar to those documented by Frantsi *et al.* (2002) for haddock raised in nearshore cages. It is likely that growth has been slowed, however, by maturation of females. Mean female GSI rose to 13% in February 2005. This percentage is indicative of mature, prespawning haddock (Clay, 1989), and this was confirmed by the presence of some hydrated eggs in all the haddock ovaries observed at this time. Fatty livers, and therefore high HSI values, have also been observed in cultured haddock, and it is thought that diets containing high amounts of lipids (>12%) cause enlarged livers (Nanton *et al.*, 2001). Our initial diets were high in lipids (>15%), which resulted in HSIs of >20%. Since changing to a new Marine Grower formulation produced by Ziegler (50% protein, 15% carbohydrate, and 15% lipid), the mean HSI has decreased to 13.4%. While some of this decrease was almost certainly associated with the decrease in dietary lipid, probably some decrease in the mean HSI has been the result of the mobilization of lipids out of the liver during vitellogenesis.

Early maturation of some haddock, video communication problems during winter months, and overfeeding by the auto feed buoy resulted in a gross FCR of 2.36. More recently, the project has integrated new real time video technology from the haddock cage back to the University. The new video communication link has greatly aided in monitoring feeding behaviour, and should reduce the feed conversion ratio during the remaining growout period. The SGR in the nearshore pens was 1.7% d^{-1} compared with 0.35% d^{-1} at the offshore cage. The rapid growth rate nearshore was the result of the smaller initial size of the fish (16.7 g), shorter duration in the nearshore pens (3 months), and warm-water temperatures during this period (6–14 °C). The SGR offshore was calculated from bigger fish, covered a span of 23 months, and included winter temperatures as low as 1.3 °C.

Results with culturing both cod and haddock in offshore submerged cages have been encouraging. Growth and feed conversion compare favourably with those of fish grown in inshore surface cages, and the multiple transferring of fish has resulted in little to no mortality. In addition, we have not observed any disease issues at the open ocean farm. In our view, the principal advantage of submerged culture is the more stable thermal environment experienced by the fish. For example, surface waters in New England can reach nearly 20 °C during summer, while water below the thermocline (10–12 m) rarely exceeds 12–13 °C. Thus, fish in submerged culture avoid the sub-optimally warm surface temperatures that would be experienced by fish in more conventional surface cages.

While encouraging, successful commercial-scale production will depend on the availability of juveniles, delaying sexual maturation, the development of larger volume, less expensive cages, and the development of larger feeding systems able to withstand offshore conditions. Given these,

the economics of cod and haddock production in submerged, offshore cages becomes more attractive.

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